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THESIS

BENEFITS OF A HOSPITAL TWO-BIN KANBAN SYSTEM

by

Andrew S. Olson

September 2014

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13. ABSTRACT (maximum 200 words)

Managing the distribution of medical supplies to clinical units within a hospital is a key component of a hospital's administrative costs. In an attempt to control costs, Walter Reed National Military Medical Center (WRNMMC) installed a two-bin kanban system across multiple departments. In this thesis, we analyze the effectiveness of the kanban system from two viewpoints: *organizational benefits*—defined as the process of organizing the supply-chain into the two-bin kanban system—and *inventory benefit*—defined as the effects of staging the resupply in a two-bin fashion. We analyze two years of data, across twelve departments, comprising almost 375,000 items ordered. The results show significant organizational benefits to the hospital overall, and a steady-state in inventory costs. The data did not show consistent results across individual departments, with departments experiencing increases, decreases, and steady-states for both benefits. Additionally, we note that there is further room for WRNMMC to exploit the kanban system's ability to optimize inventory sizes via the two-bin kanban process.

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BENEFITS OF A HOSPITAL TWO-BIN KANBAN SYSTEM

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ABSTRACT

Managing the distribution of medical supplies to clinical units within a hospital is a key component of a hospital's administrative costs. In an attempt to control costs, Walter Reed National Military Medical Center (WRNMMC) installed a two-bin kanban system across multiple departments. In this thesis, we analyze the effectiveness of the kanban system from two viewpoints: *organizational benefits*—defined as the process of organizing the supply-chain into the two-bin kanban system—and *inventory benefit*—defined as the effects of staging the resupply in a two-bin fashion. We analyze two years of data, across twelve departments, comprising almost 375,000 items ordered. The results show significant organizational benefits to the hospital overall, and a steady-state in inventory costs. The data did not show consistent results across individual departments, with departments experiencing increases, decreases, and steady-states for both benefits. Additionally, we note that there is further room for WRNMMC to exploit the kanban system's ability to optimize inventory sizes via the two-bin kanban process.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHRMM	Association for Healthcare Resources & Material Management
BRAC	base realignment and closure
BUMED	Bureau of Navy Medicine
CSV	comma separated value
DFAS	Defense Financial Accounting System
DMLSS	Defense Medical Logistical Standard Support
DoD	Department of Defense
EOQ	economic order quantity
ER	emergency room
FIFO	first in, first out
JHUAPL	John Hopkins University Applied Physics Lab
JIT	just-in-time
MOR	main operating room
MICC	maternal infant care center
MHS	military health system
MTF	military treatment facility
PACU	post-anesthesia care unit
PAR	periodic automatic replenishment
RFID	radio-frequency identification
RTLS	real-time location system
WRNMMC	Walter Reed National Military Medical Center

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EXECUTIVE SUMMARY

Under the Base Realignment and Closure Act of 2005, the Department of Defense was required to combine the Walter Reed and Bethesda National Naval Medical Center to form the newly renovated/realigned Walter Reed National Military Medical Center (WRNMMC). One of the difficulties during integration was the presence of logistical challenges. To eliminate these challenges, the Bureau of Navy Medicine implemented a two-bin kanban system.

Two-bin kanban is an attempt to bring a level of optimization to product availability while trying to minimize cost to the supply-chain system. In a two-bin system, product inventory is placed into two bins—primary and secondary—that addresses the rate of consumption and reorder time. When the primary bin is empty, a reorder is triggered, and product is consumed from the secondary bin until the new supplies arrive. The bins are expected to regularize the intervals between ordering, regularize the amount of product being ordered, reduce the quantity of product on-hand as it sensitizes the supply-chain to demand, and organize the products for consumption and resupply. Through all these effects, it is assumed that there will be a reduction in costs. It is these effects that we attempt to analyze in this thesis.

The results are based on twenty months of data, constituting approximately 328,000 daily supply transactions, obtained from WRNMMC's Defense Medical Logistics Standard Support (DMLSS) servers. The data is divided from before and after the implementation of the kanban system in each hospital department to measure the effects of change to the costs of supplies ordered.

The effects of the kanban system is measured in two ways—*organization benefit* and *inventory benefit*. The *organization benefit* encompasses the effort the kanban system makes to bring more order and control to the logistical process. The *inventory benefit* is an attempt to capture the benefit of regularizing the order process, and controlling the on-hand inventory amounts.

The data we analyze shows some improvement delivered by the kanban system, but is inconclusive to show improvement across all areas where we expect to see improvement. Figures 1 and 2 represent the summarized effects for the *organization* and *inventory benefits*, respectively. From all this, we conclude, first that there are clear *organizational benefits* to the hospital overall. This is not true on a per-department level, but it is true of the most expensive departments. Second, explored in more detail in the thesis is the opportunity for exploiting the kanban system to optimize inventory sizes, also known as economic order quantity (EOQ). The current system at WRNMMC does not implement EOQs per item per department. However, the kanban system provides a perfect framework to implement EOQ, thus minimizing operating costs of the logistic system. We recommend that EOQs be explored in future refinements to the kanban system.

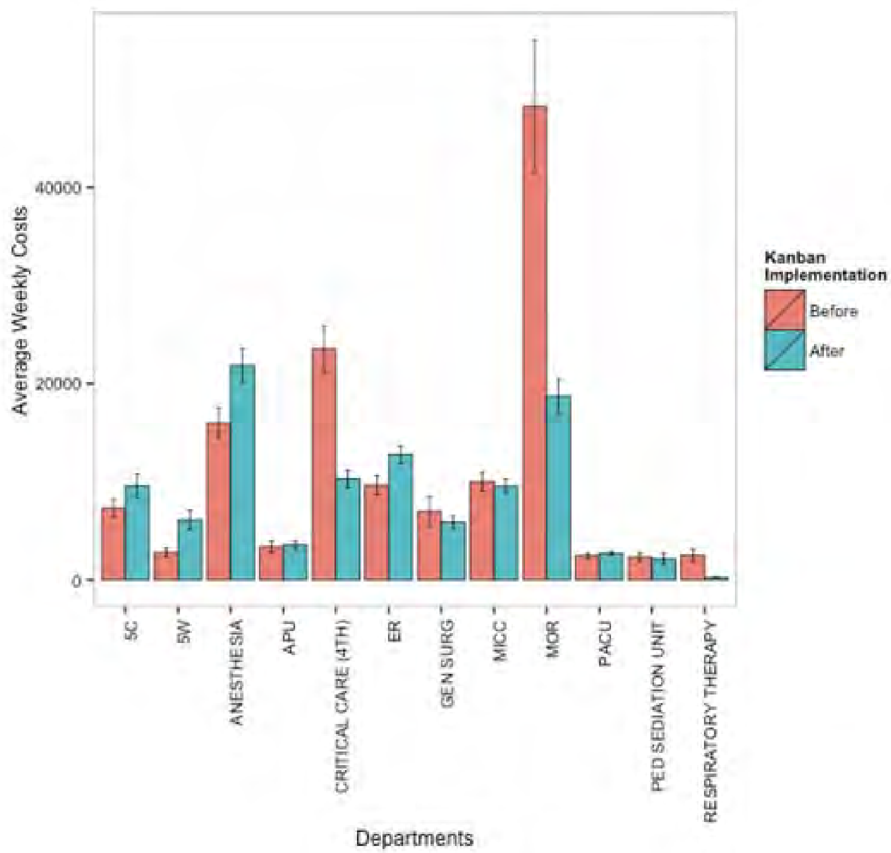

Figure 1. Summary of *organization benefits* for the departments analyzed.

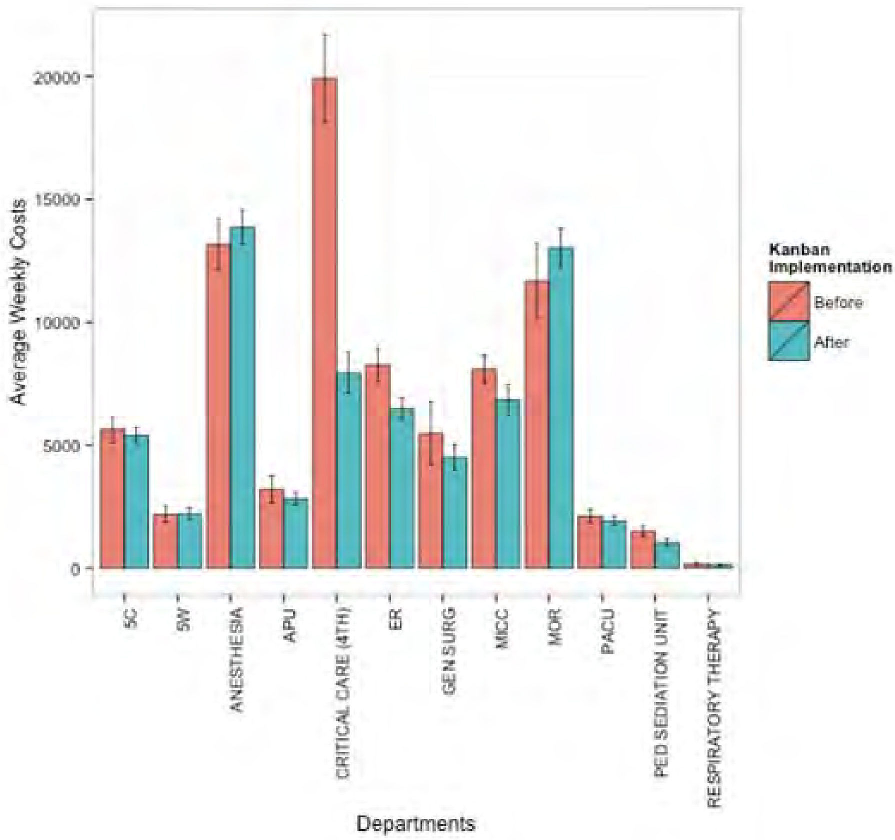

Figure 2. Summary of *inventory benefits* for the departments analyzed.

Outside of the results, there were aspects of this kanban system that were not analyzed. Though discussed briefly during the overview of the kanban system, the aspects of the radio frequency identification (RFID) capabilities of the two-bin kanban system were not addressed in this thesis. The greatest impact that the RFID capabilities would have will be on reducing the involvement of humans within the supply-chain loop. There are potential savings of the RFID two-bin kanban system to reduce the time spent by clinicians and material handlers in the supply-chain process. The data analyzed did not cover this or any portion of the cost-savings attributable to reducing the amount of manpower dedicated to the supply-chain. Therefore, it was not analyzed. However, we believe that further analysis involving the order costs, the manpower reduction in ordering, and EOQ would highlight further potential for the kanban system to improve the logistics process.

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Each of us has circles of friendships and within those lie the portion of the human family whom God has given to us to love, to serve and to learn from. Within each of our circles of friendships there lie so many opportunities to love, to serve and to be taught. None of us fully utilizes these people-opportunities allocated to us. However, when partially or fully utilized, these become the bedrock of a strong human foundation. Fortunately, I have felt, at least in part, that I have been able to utilize some of these opportunities to love, serve and learn from. And after leaving here, my foundation feels a little surer.

Specifically, this would not have even been attempted without the love I feel from my wife, Heather. She will forever remain a major foundation in my life. Children often make you appreciate the littlest things life offers, and so to Spencer, Kate, and Olivia, I thank you for sharing with me great happiness. Family is the greatest circle any of us can participate in and I am grateful to all in my family—both near and far. Professionally, Prof. Nedialko Dimitrov and Prof. Rachel Silvestrini provided a depth of understanding and questioning on many fronts and I thank them for their guidance. Finally, to the friendships that I gained from my fellow officers here at NPS; we laughed, we yelled, we ate good food, we smelled weird things (mostly Mike), and eventually we conquered. Thank you for the joy that you helped me find in the journey.

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I. INTRODUCTION

A. BACKGROUND

Under the Base Realignment and Closure (BRAC) Act of 2005, the Department of Defense was required to combine four National Capital Region impatient hospitals—Walter Reed, Bethesda National Naval Medical Center, DeWitt Army Community Hospital, and Malcolm Grow Medical Center—into two hospitals without losing any functioning patient care capacity. All tertiary services from Walter Reed were required to be combined with the Bethesda National Naval Medical Center to form the newly renovated/realigned Walter Reed National Military Medical Center (WRNMMC). The remaining primary and specialty care services from Walter Reed were absorbed by the expanded DeWitt Army Community Hospital—now known as Fort Belvoir Community Hospital (BRAC Commission Report, 2005).

In 2009, the John Hopkins Applied Physics Lab (JHUAPL) was contracted to focus on the integration of the material handling and logistics for WRNMMC's main operating room. During their investigation, the following issues were discovered:

- Replenishment was handled by a rotating and temporary staff.
- Current process demanded a daily inventory of each item. Due to the effort required with counting, cart techs are simply "eye-balling" the bin locations leading to inventory accuracy concerns (out of stocks, topping off, and overstocking).
- Replenishment quantity varies drastically on usage, creating opportunity for replenishment error.
- Inventory expiration was not managed to eliminate the frequency of expired items.

These results impacted the way in which the clinic interacted with the supply department and the replenishment system. In particular, the staff started to "own" the reorder process by ordering more items than necessary to ensure product on-hand. Furthermore, some of the clinical staff performed part of the logistical functions that were assigned to the logistic staff (Ward, T. personal communication, 16DEC13).

B. PROBLEM STATEMENT

To eliminate these logistical challenges the Bureau of Navy Medicine (BUMED) along with its contracted partner JHUAPL, searched and analyzed several different options. After a cursory review, JHUAPL recommended the implementation of a Radio-Frequency Identification (RFID) two-bin kanban system. This was recommended due to the relative simplicity of the replenishment process and can be easily standardized across the military medical enterprise. It also improved the stock rotation process enabling first-in/first-out (FIFO) ordering, it automated the process for generating and tracking orders, it minimizes clinical involvement in supply chain activities, the storage system can be flexible, and it requires limited facility modifications (Beasley, R., personal communication, 18OCT13). BUMED implemented this logistical process across twenty-five departments or clinics at WRNMMC. Believing that they have developed a significant improvement in the handling of medical supplies and a potential cost-saving process, BUMED has begun the procurement process to implement this at ten other naval hospitals. However, before the procurement process is complete, BUMED has sought an analysis on the effectiveness and potential cost savings of this program. The goal of this thesis is to provide BUMED with an analysis of the two-bin kanban system at WRNMMC to see, if any, improvements were made in the supply chain process.

C. THE KANBAN PROCESS

Developed by Toyota, a kanban system tracks the authorization and movement of product from the supplier to consumption locations. The general kanban process in a healthcare setting proceeds in the following manner. Stock quantities are split between the primary and secondary bins in each supply location (see Figure 1). Products are initially taken from the primary bin. Once the primary bin is empty, the clinician attaches the tag to the RFID board to signal an empty bin and begins resupply of the stock. In the interim, product is taken from the secondary bin, which is designed as a buffer for the resupply process. If the secondary bin is empty, the clinician attaches the appropriate tag to the RFID board, which is an indicator of no product in the department—which then can be used as a signal for a possible emergency order (see Figure 2). As new stock arrives, any product remaining in the secondary bin is placed in the primary bin, ensuring a FIFO process. The supply system then resets by replacing the associated tags for each bin from their place on the RFID board (Bendavid et al., 2010).

Figure 1. Example of stocks split between primary (in front) and secondary bins (directly behind). RFID tags are placed on the front of each bin. Photos taken at WRNMMC on 16DEC13.

Figure 2. Example of RFID tags placed on the RFID board that signals items in need of replenishing. Colored RFID tags distinguish secondary bins. Photos taken at WRNMMC on 16DEC13.

The kanban system has several benefits. Under this type of logistical process, the information flow changes from push to pull, allowing the supply system to track consumption data. In a pull system, material is only sent when there is an identified need, while in a push system, materials are sent when they are available to the supplier (Bendavid et al., 2010). As is discussed in further detail in the next chapter, further benefits include: a no-count replenishment system—eliminating costly manpower hours; reduced average inventory levels; reduced time to reorder a product; and reduced risk of expiring products, among others (Landry & Beaulieu, 2010).

D. THESIS OUTLINE

The second chapter reviews previous literature in the health care logistical field. The third chapter describes the data used to analyze the kanban system at WRNMMC. The fourth chapter provides an analysis of results of the data exploration. The final chapter presents a discussion on the analysis including conclusions and recommendation for future work.

II. LITERATURE REVIEW

Managing the distribution of medical supplies to clinical units within the hospital has been shown to be a key component of a hospital's administrative costs (AHRMM, 2010). Hospitals have pursued various systems as they search for a way to eliminate the costs associated with distribution of supplies. Initially, hospitals began with a simple requisition system, this moved to exchange carts and then the systems switched to par levels. The two-bin or kanban system emerged in Denmark and Holland at the end of the 1980s in hospitals. Rather than having material handlers drawing on their experience or guessing by looking at the material in stock (i.e., par levels), they could scan labels that had been removed from empty bins and placed on a board on the wall within each clinical storage unit (Leone & Rahn, 2010). Noticeable gains were made from switching to the two-bin system but not at the expense of increasing the inventory (Landry & Beaulieu, 2010). The two-bin system also encouraged the rotation of stock reducing the risk of expiring products. It additionally provided greater control on order quantities and enabled a variety of products stored in the same storage unit (Landry & Philippe, 2004).

Several other systems were introduced after the initial two-bin kanban system. These include the automated storage cabinets, which were developed as a way to reconcile patient consumption with supplies. This shrank in popularity, especially in the United States, because of the movement to diagnostic-related groups for billing (Landry & Beaulieu, 2010). Another emergence was the weight control bin solution for general supplies. Adapted from the industrial sector, this system automatically triggered a reorder using point order logic. This system faced challenges because it required large uses of space and reinforcement of walls to hold the bins (Landry & Beaulieu, 2010).

Throughout all the inventory management systems there is some use of either a fixed-interval reordering process, order point logic, or a combination of both. This means that the review period duration, maximum inventory level, order point, reordering quantities, and safety stock are calculated using stochastic inventory models. These techniques are utilized to explore the balance between ordering costs and inventory carrying costs. Effectively managing these inventory parameters can lead to improved performance (Landry & Philippe, 2004). However, to many hospitals' detriment, guess-work prevails, demand is not tracked effectively and little-to-no parameterization is kept (Landry & Beaulieu, 2010).

Hospitals continued to search emerging technologies to confront rising costs. In the early 2000s, the use of RFID-enabled tools began to materialize in the supply chain management market. The application of RFID technologies was seen from high-valued item traceability to asset tracking—or Real Time Locating System (RTLS)—which can include equipment, medical staff and/or patients. This marriage of RFID technology culminated in the mid-2000s with the union of the two-bin kanban system with RFID (Landry & Philippe, 2004). The addition of RFID technology further improved the two-bin system by eliminating the need to conduct rounds of the nursing unit to scan the labels of empty bins, thus doing away with additional manpower hours with little or no disruptions on the clinical units (Landry & Beaulieu, 2010).

In 2009, Natchman and Pohl, from the Center of Innovation in Healthcare Logistics at the University of Arkansas, in association with the Association for Healthcare Resource & Material Management (AHRMM) conducted a survey to try to quantify the current state of logistics in terms of cost and quality (Nachtmann & Pohl, 2009). In their report, the authors note that close to thirty-two percent of a healthcare institution's annual operating costs is being spent in support of the supply chain system (supporting inventory and order management). Research by others has put the cost ranges for healthcare logistics between twenty percent and forty-six percent of an institution's operating budget (Chow & Heaver, 1994; and Network, 2007). This suggests that many of the opportunities that the new technologies have created for the supply chain management field was either not being utilized or was not fully reaching its potential.

Bendavid (2010) noted that many of the developments and organizing benefits of these technologies are still in their infant stages. Though the research and organizing benefits of these ideas have been fully developed in other sectors of the economy for years (Sarac, Absi, & Dauzere-Peres, 2010), there is very limited scientific research that fully develops the uses of the RFID two-bin kanban system in the modern healthcare supply chain process (Kumar, Swanson, & Tran, 2009).

Over the years, coinciding with the supply chain management improvements, there was a general emergence of thought in healthcare called *lean thinking*. Introduced in the automobile manufacturing industry, it consists of eliminating any source of *waste* while ever searching for opportunities to increase productivity or value (Black & Miller, 2008). The definition of *waste* has been generalized to ensure inclusion of any activity that consumes resources without providing sufficient value to warrant such an activity. Examples include processes that create bottlenecks in the system, overstocking, unnecessary movements of products or personnel, errors leading to rework, and so forth. The growth of this process improvement analysis has seen enormous success in the healthcare sector, especially in the last decade (de Souza, 2009).

Since 2010, the two-bin kanban system with RFID capabilities has reemerged as the logistic inventory system of choice. Landry and Beaulieu generalized the *lean* aspects of the two-bin system with the following benefits: no-count replenishment system; reduces the average inventory level; increases the quality of information at the point of use; reduces the time taken for the ordering process and thus reduces the time spent by material handlers in the clinical units; reduces product handling and increases event-related sterility (infection control); reduces the risk of products expiring (stock rotation); and manages products with different replenishment cycles in the same storage units (Landry & Beaulieu, 2010).

Bendavid et al. (2010) have shown that as these technological advances have married up with the notions of *lean production*, it has provided promising results. However, many hospitals have yet to parameterize their inventory levels, nor do they track the productivity gains from logistical processes improvements, inventory shrinkage and optimization of inventory levels. By doing so, there will be significant changes and notable savings related to the type and quality of work performed by the nursing staff, which leads to indirect improvements in the quality of care as clinical staff will have more time available for patient needs. Among all these process improvements, there is lacking quantitative analysis to support these statements and clear quantitative evidence that shows the benefit of the two-bin kanban system in a healthcare setting. This is the aim of this thesis.

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III. DATA

The data set for the study of this problem was obtained from WRNMMC's Defense Medical Logistics Standard Support (DMLSS) servers via personnel at that command. The data was delivered via Microsoft Access tables and is coerced into comma separated value (CSV) format for easier entry into the R software package. For this data set, each row contains the DMLSS customer identification code (usually representing a particular department), order date (daily), the product identification code, product description, product amount ordered, product amount cancelled (usually zero or *NA*), total units of product ordered or volume (the value of *product amount ordered* minus *product amount cancelled*), unit product price at the time of order, and total dollar amount of product ordered (see Table 1 for an example). For the period under examination, the data represents a daily transaction history for the departments analyzed. The initial data set consists of approximately 328,000 records. Furthermore, the customer identification code was matched to commonly held name descriptions. For example, DFBA03 is a customer identification code for the Main Operating Room (MOR).

Customer ID	Order Date	Item ID	Item Description	Quantity Requested	Quantity Cancelled	Volume	Unit of Price	Order Total
AAAA00	1/1/2011	07062B1323Q	SODIUM CHLORIDE 0.9% 500ML	12	NA	12	$16.32	$195.84
ABDA00	8/24/2011	338007704	DEXTROSE 5%-SOD CHLORIDE 0.2% 1000ML	5	NA	5	$9.60	$48.00
DFBA03	2/16/2011	DP1022	MATRIX DURA MATER COLLAGEN 2X2IN ENHANCE	4	1	3	$348.00	$1,044.00
DFBA16	3/23/2011	PXMK2160	TRANSDUCER	2	1	1	$256.50	$256.50
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 1. Example of the data set

A. DMLSS

DMLSS is a joint interoperable automated information system that supports medical logistics activities within the military health system (MHS). DMLSS is the primary support system for all military logistics functions associated with military medical treatment facilities (MTFs) worldwide. DMLSS captures the following logistical functions: requisition, acquisition, procurement, shipment, receipt, storage, distribution, and disposal of medical supplies. DMLSS integrates with other Department of Defense (DoD) systems such as Defense Financial Accounting System (DFAS) to help with the tracking of expenses by department and other cost accounting functions.

1. DMLSS Limitations

As mentioned, DMLSS main objective is related to the logistics—be it physical or financial—of medical supplies. Thus, the nature and process of accounting the material to each department in the MTF do not always correspond to other military or medical systems. There are other systems that contain particular corresponding information that makes it difficult to sync the data. As an example for this data set, DMLSS assigns the obstetrics and gynecology outpatient clinic, the neonatal intensive care unit, and the maternal/infant care unit under the same DMLSS customer identification code. This makes comparing workload data, where each of the three areas is separated in many other data systems, difficult, if not impossible. This is explored further in the next two chapters.

Furthermore, DMLSS attempts to be an all-encompassing medical logistical software system. Inherent in a system that attempts to capture such entirety is an abundance of information. In this instance, the data set is capturing more information than is wanted. For WRNMMC, the kanban system is set up to be replenished solely with products that have been purchased through the hospital's central warehouse. However, each department has the capability to purchase items on a *by department* basis, if such an item does not meet the criteria (typically, minimum order quantities) for being ordered and stocked via the central warehouse. These individual purchases are logged, ordered, tracked, and receipted through DMLSS. The handling of these items will be discussed in detail in Chapter IV.

Finally, as previously mentioned, the data set is a daily purchase log history of departments over time. Because of the nature of the data, where each line represents a transaction on a particular date for a particular item, it is expected that there will be days when no transaction has occurred for a department, especially a smaller department.

Unfortunately, within the original data set there are blocks of missing data, where several departments had months of the purchase log history missing. Of the twenty-five departments/clinics that underwent the change of the kanban system, thirteen had at least one month of the data missing. Several attempts were made to determine the nature of the corruption of the data and restore the data to its entirety, however these attempts were not successful. It was therefore determined to focus the analysis only upon those departments/clinics where the data set is complete over the study period.

B. STUDY PERIOD

The defined study period is from at least twelve months prior to the implementation of the two-bin kanban system to at least twelve months after. The system was implemented across the various departments of WRNNMC over a five-month time span—from February 2012 to June of 2012—with the majority of the departments having their organizing benefits dates in the months of May/June 2012. Therefore, the dates of data collection are from January 1, 2011 to August 30, 2013.

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IV. ANALYSIS

This chapter discusses the steps and methods taken in analyzing the two-bin kanban system. We begin by discussing the several preparatory steps performed on the data prior to final analysis of the benefits of the kanban system. The next section discusses the way we dealt with fact that this is time-series data. The third section presents the essence of the cost analysis and introduces two avenues or ways to analyze the effects of the two-bin kanban system—these two effects include *organizing benefit* defined as the process of organizing the supply-chain into the two-bin kanban system and *inventory benefit* defined as the effects of staging the resupply in a two-bin fashion—and their results. The third section concludes with a summary of the results. In this chapter, we simply present the statistical figures and we reserve discussion and explanation of these results for the next chapter.

A. DATA PREPARATION

There are four nuances in the data set that need to be fixed before analysis begins. First, over the course of the thirty-two-month time span, the individual price of an item fluctuates. In an attempt to properly account for this fluctuation, the average price for each item over that span was used as per unit costs. This per unit cost was then multiplied by the amount of products ordered to get the total cost of product ordered each day by a department for that particular day. For example, the price of one item per unit went from \$72.86 to \$73.37 to \$77.96 to \$72.45 to \$76.98 over the time period. In order to smooth the data, the average price over all the data points, in this instance \$74.74, was utilized as per unit costs.

Second, in the course of initial discovery of the data set, there appeared to be several items that were ordered ten times or less over the entire time frame. There could be several explanations for the appearance of such items in the data set, as mentioned in Chapter III—the use of DMLSS as a logistics system with departmental purchasing authority outside of the central warehouse stores. Nevertheless, it appears very unlikely that these items are being stocked and ordered via the central warehouse, due to the minimum ordering requirements for the central warehouse buying protocol, and thus affected by the kanban system. Therefore, these items were removed from the data set.

Thirdly, of those remaining items, the analysis was narrowed to those that were considered part of the Pareto principle. Named after the Italian economist Vilfredo Pareto and also known as the 80–20 rule, the principle states that for many events, roughly eighty percent of the effects come from twenty percent of the cases. Taking this rule into account, items were ranked highest to lowest by total cost of product ordered over the total time span. From the top of this list, we keep the items that account for eighty percent of the total cost over the study period. An example of this can be seen in Figure 3 for one department.

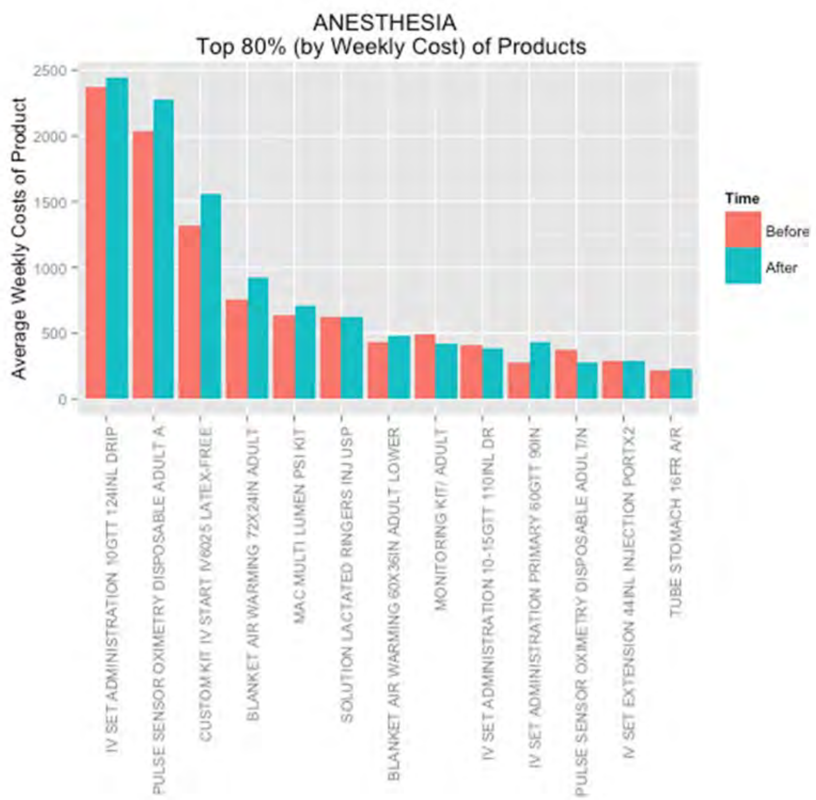

Figure 3. Example of Pareto Effect for the Anesthesia Department. Only 13 of 132 items account for eighty percent of the total cost of the department. We use these 13 key items to estimate the benefits of the kanban system.

Finally, attempting to capture the effects of the kanban system's characteristics, each item's average weekly costs are split to compare the effects of before and after organizing benefits, also seen in Figure 3. When this division occurred, there were several items ordered before the organizing benefits but not after or vice versa. To account for these phenomena, items were retained only if they were present before and after the kanban system was installed. Additionally, when items were divided, it was discovered that several were hardly ordered before but significantly increased in ordering afterwards or vice-versa—to the effect of several degrees of magnitude. Believing that this was due to extemporaneous circumstances outside the effects of the kanban system's introduction, we limited the degree that these items affected the analysis. This was handled by requiring at least five percent of the average weekly cost of each item before the implementation of the two-bin kanban as opposed to after. Likewise, items that exceeded three hundred percent of the average weekly cost after as compared to the before were also eliminated from the analysis.

B. ANALYZING TIME-SERIES DATA

The data set represented a daily log of transaction over several months. In analyzing the data there were several factors that presented themselves. First, we must appropriately smooth the data to account for daily fluctuations. This is discussed in the first section. Next, we address a general trend in the data set that was observed for all departments. This is addressed in the second subsection.

1. Aggregation of Data by Week

One way to manage large time series data is by binning the data into time intervals that aggregates over days, weeks, months, etc. Depending on the aggregation within the analysis of the data, noise can be smoothed, which would allow trends to appear—be they seasonal or otherwise (Maciejewski, 2011). However, too much aggregation or smoothing removes any noticeable patterns in the data and eliminates the ability to sufficiently extract results. In the case of this data set, we choose to bin the data by a week (as opposed to by day, multi-day, multi-week, or month) which eliminated the noise of the daily purchase logs and revealed a smoother purchase pattern. Choosing the proper binning of data sets becomes particularly more important when the effort of the analysis is to attempt forecasting through time-series modeling. Though time-series modeling is not the focus of this thesis, the size of the bin has an influence on the node analysis and has a role in the statistical analysis performed thereafter. Therefore, it is noted for the reader.

2. Increases in Total Costs before Implementation

From a macro level, analyzing purchasing patterns for all the departments by item revealed an issue with the data. In almost every case, when looking at the frequency in which an item is ordered over time, there appeared to be a significant increase in total costs for ordering the item before the organizing benefits of the kanban. This can be seen in Figure 4, where the weekly frequency is plotted against time up to the point of kanban organizing benefits for the item. If this pattern is pervasive across all items, ascertaining the shift in ordering frequency and when it happens is necessary. Change-point analysis is used to determine statistical shifts in the frequency of purchases.

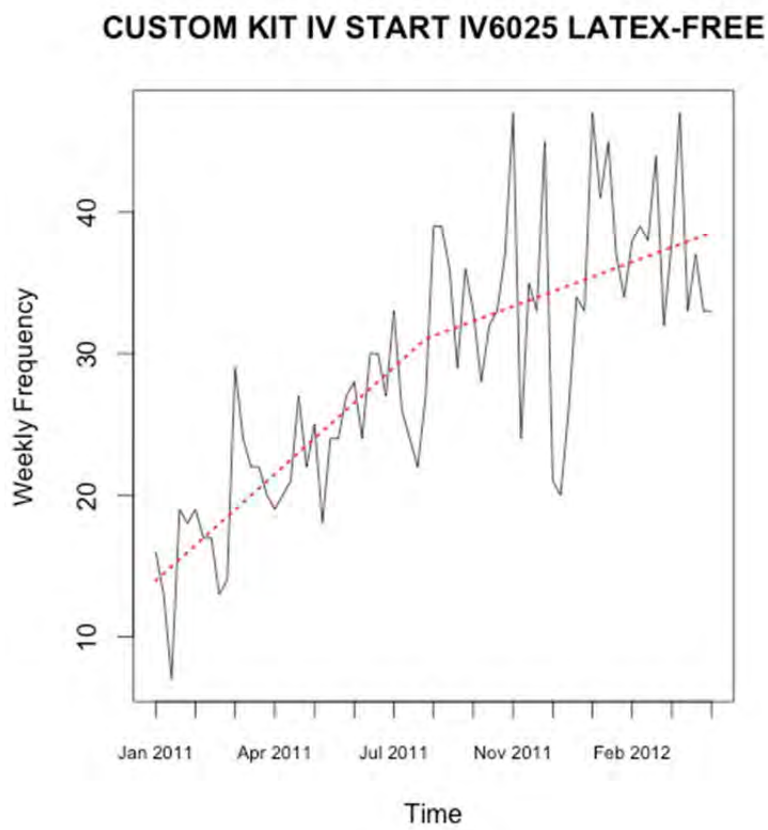

Figure 4. Plot of the frequency of an individual item for all departments over time, where time is plotted from the start of the study period to just prior to the kanban system organizing benefits.

Change-point detection is the term specified to the problem of estimating the point at which the statistical properties change in a sequence of observations. In a formal manner, if $y_{1:n} = (y_1, \ldots, y_n)$ represents a sequence of data in ordered form. A change-point is said to exist at time, $\pi \in \{1, \ldots, n-1\}$, such that the properties of $\{y_1, \ldots, y_\pi\}$ and $\{y_{\pi+1}, \ldots, y_n\}$ are no longer statistically similar. The null hypothesis is the maximum log-likelihood, i.e., $\log p\left(y_{1:n} \mid \hat{\theta}\right)$, where $\mathrm{p}(\cdot)$ is the probability density function associated with the distribution of the data and $\hat{\theta}$ is the maximum likelihood estimate of the parameters. For the alternative hypothesis, a model with a change-point at π is considered, where $\pi \in \{1, 2, ..., n-1\}$. Then the maximum log likelihood for a particular π is

$$ML(\pi) = \log p\left(y_{1:\pi} \mid \hat{\theta}_1\right) + \log p\left(y_{(\pi+1):n} \mid \hat{\theta}_2\right).$$

Due to the discrete characteristics of the change-point location, the alternative maximum log-likelihood value is simply the $\max_{\pi} ML(\pi)$ over all possible change-point locations. The test statistic is then

$$\lambda = 2\left[\max_{\pi} ML(\pi) - \log p\left(y_{1:n} \mid \hat{\theta}\right)\right].$$

Finally, the test is then choosing a threshold, c, such that the null hypothesis is rejected if $\lambda > c$. If the null hypothesis is rejected, then the estimate of the change-point is the position of $\hat{\pi}$, the value of π that maximizes $ML(\pi)$ (Killick & Eckley, 2014). What values c should take is still an open debate in academia with several authors providing criterion. See Guyon and Yao (1999); Chen and Gupta (2000); Lavielle (2005); Birge and Massart (2007) for further discussions on appropriate values of c.

As the kink in the dashed line in Figure 4 indicates, a change-point occurs at the end of the summer of 2011 for this item. This coincides with the final push of patients from the closing of the old Walter Reed Medical Center to the new WRNMMC. The old Walter Reed Medical Center officially closed its doors on September 1, 2011 (Koran, 2011). Though many patients were transferred or moved in a phased approach, this final push appears to have an effect on the frequency of products ordered. In analyzing this affect across all items, a histogram is created (shown in Figure 5) where the change-points, referred to as *knots* or *breakpoints*, of each item is binned according to its corresponding date. Finally, a density plot overlays the histogram to show the shape of the change-point distribution, see Figure 5.

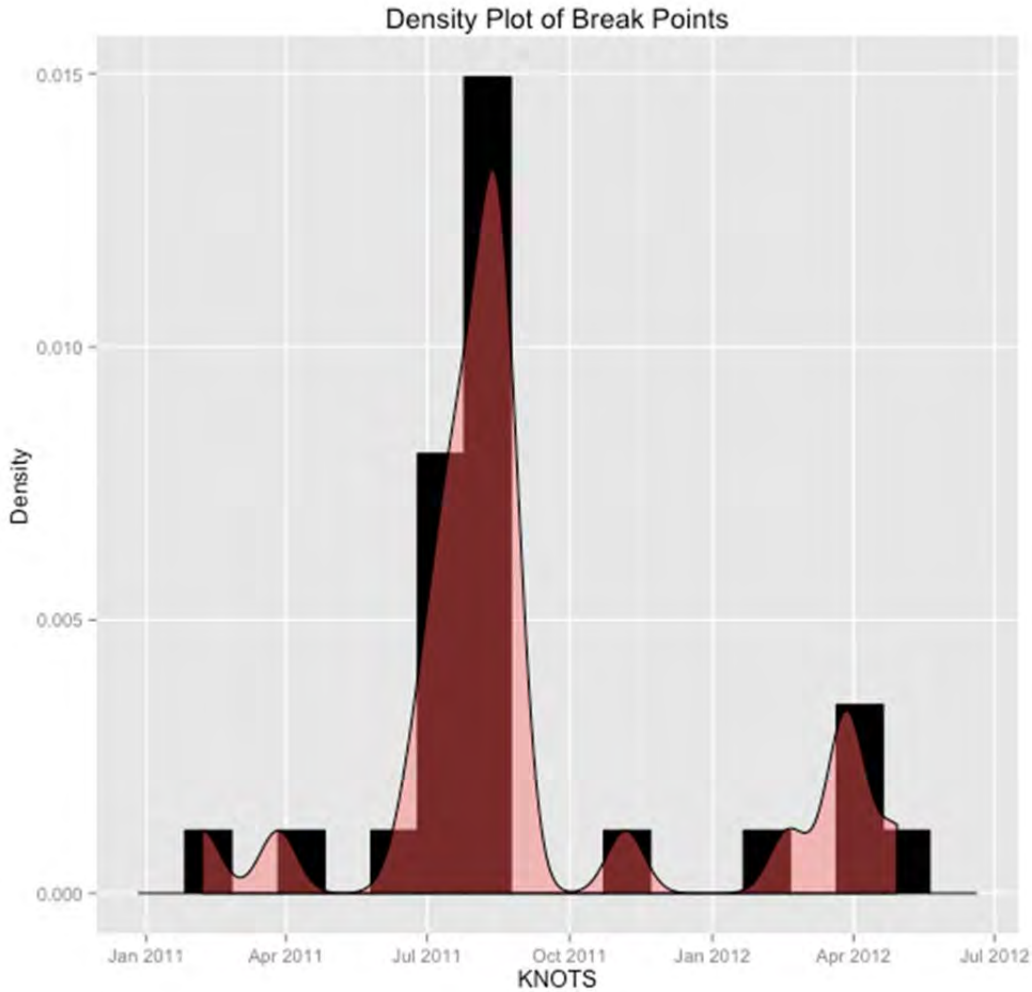

Figure 5. Histogram and density plot overlay of frequency change-points for all items. This plot indicates a significant change for most items around August of 2011.

Given the information in the density plot, we conclude that there is a significant increase in order frequency through the summer of 2011. To eliminate the bias that the build-up causes, all the data is eliminated previous to September 1, 2011 and this date is the new start date for the data set.

C. COST ANALYSIS

The goal of this analysis is to quantify, in some way, the effects of implementing a two-bin kanban system. There are two possible benefits that are provided by implementing the two-bin kanban system. The first comes from the nature of a focused initial improvement in organizing and ordering the supply-chain process. Any effort that is made to bring more order and control to the logistical process should provide benefit and we analyze those effects. The second benefit is in how the two-bin kanban system functions. Does the actual design of having two-bins with the kanban card as a resupplying indicator provide benefits to the supply-chain system? This is also analyzed to see its effects to the supply-chain process. Therefore, for clarity we refer to these two possible benefits as *organizing benefits* and *inventory benefits*.

In narrowing the analysis, the natural parameter to focus on is how much money is spent on supplies before the kanban system as compared to after. This then, encompasses the next section, where we analyze to see how much is spent before and after the system is implemented—keeping the two benefits, *organizing benefits* and *inventory benefits* in mind. However, before analyzing on a department level, we first formalize the test statistic, describe how we will distinguish from *inventory benefits* and *organizing benefits*, and then look at all the departments together.

1. Test Statistic

The hypothesis that is tested in each case, no matter the distinction in benefits, is the presence of a significant difference in the mean of costs after the change from before. This is formalized here:

$$H_0 : \mu_B - \mu_A = 0$$
$$H_A : \mu_B - \mu_A \neq 0 \quad ,$$

where the mean of the costs before organizing benefits, μ_B, is tested to see if it is significantly (statistically) different from the mean of costs after the kanban organizing benefits and/or inventory benefits, μ_A. We assume that each week in the data set is an observation of the total weekly costs for the week, $Y_1, Y_2, ..., Y_n$, which represents a random sample from a normal distribution with an unknown mean, μ, and unknown variance. The test statistic then is

$$T = \frac{\overline{Y} - \mu_0}{S / \sqrt{n}},$$

if $\overline{Y}$ and S represent the sample mean and sample standard deviation. In each of the proceeding tests, the null hypothesis is rejected if the rejection region falls in any of the following categories:

$$\text{Rejection region:} \begin{cases} t > t_a & \text{(upper-tail)} \\ t < -t_a & \text{(lower-tail)} \\ |t| > t_{a/2} & \text{(two-tailed)} \end{cases},$$

with the probability of falling into the rejection region is such that, as an example for the upper-tail, $P\{T > t_a\} = \alpha$ for a *t* distribution, where α is 0.05 (Wackerly, Mendenall III, & Scheaffer, 2008).

Traditionally, a t-test is not utilized in the presence of time-series data due to the correlation between the data points. However, the smoothing that was performed previously in this chapter allows us to assume that each of the data points are independently distributed (see Figure 6). A Durbin-Watson test was performed on each department to test for correlation among the errors. The tests revealed that only one of the departments exhibited serial correlation. Given further time, additionally attempts would have been made to explore the possible correlation between the data points. Additionally, tests for normality indicate that there is possible skewness in the data set but for simplicity we assumed normality across all departments, see Figure 7.

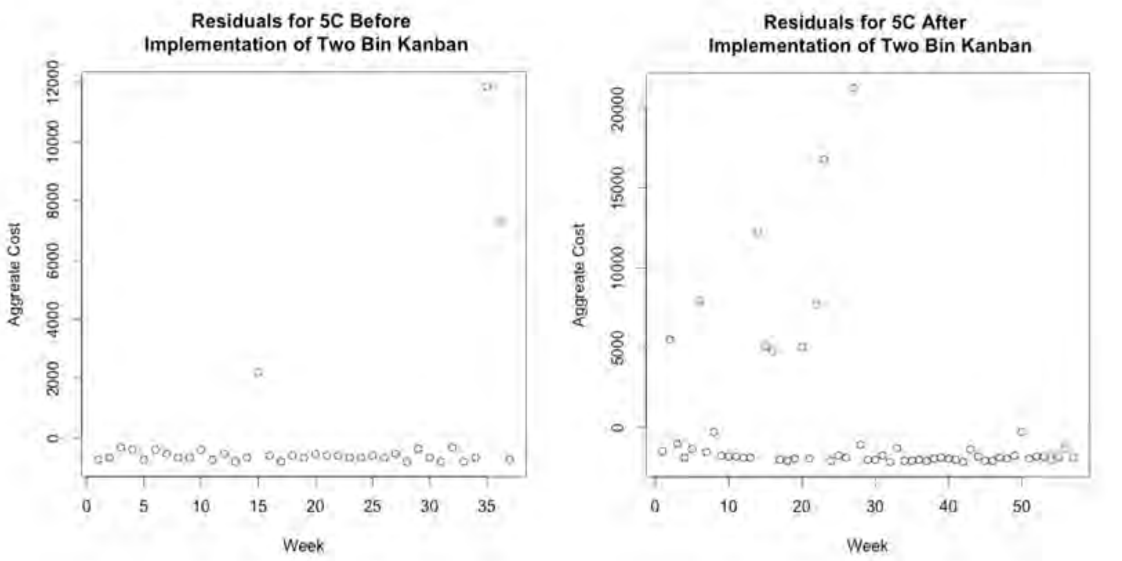

Figure 6. Plots of the residuals before and after the two-bin kanban implementation for each data point in the 5C department.

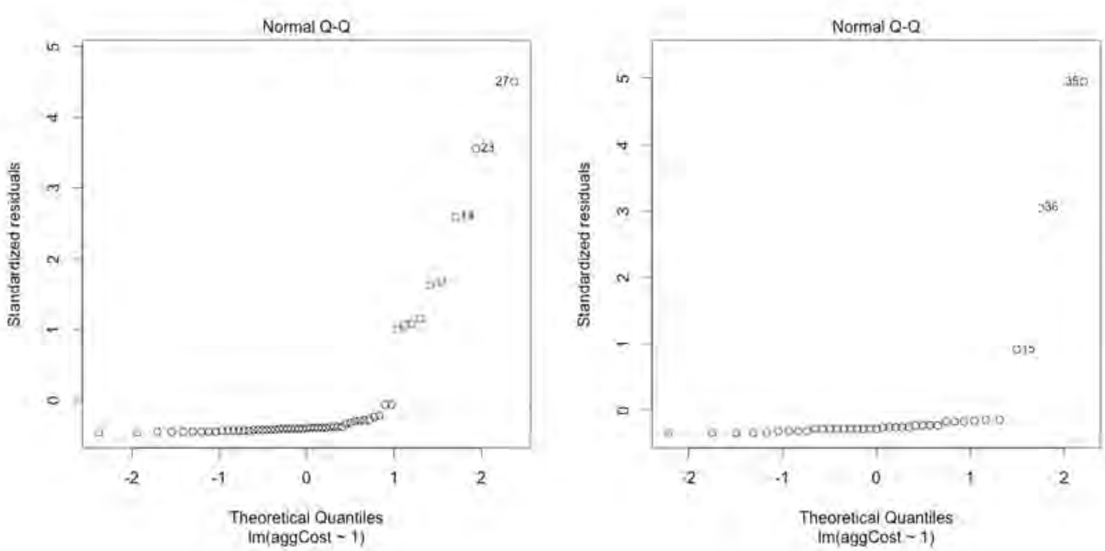

Figure 7. Q-Q plots for before and after the two-bin kanban implementation in the 5C department. The curved pattern increasing from left to right suggests the data distribution may be skewed to the right.

2. Organizing Benefits vs. Inventory Benefits

In the *Data Preparation* section of this chapter, we described four steps that were taken to arrange the data for analysis. The last two of those steps were focused more on narrowing down the data to get to the effects of the *inventory benefits* of the two-bin kanban system—the Pareto effect and the elimination of items not consistently ordered before and after the kanban system was installed. If these two steps were eliminated from the *Data Preparation*, it is believed that this would allow the effects of the *organizing benefits* to be analyzed. Justification is that in bringing order and organization to the supply-chain will reveal items that were ordered unnecessarily. Though these items do not benefit from the *inventory benefits* of the kanban—that is, having the supplies divided among two bins and utilizing a kanban card as a signal for reordering—they do benefit from *implementing* a sophisticated resupply system.

It is noted that when analyzing and presenting both effects, *organizing benefits* and *inventory benefits*, we acknowledge that there is overlap in the data. However, we believe it a mistake to ignore the effects of the *inventory benefits* without the analyzing the *organizing benefits*. If the analysis were to solely focus on the *inventory benefits* of the two-bin kanban system, it would neglect the basic benefits that the organizing benefits attempts to bring—order, as can be seen visually in Figure 8. Likewise, the two-bin kanban system *inventory benefits* are much more than a fancy attempt of organizing the supply closet. Therefore, we present both in the analysis to show the effects of one as well as the other.

Figure 8. Image that reflects the order and organization that two-bin kanban brings to the logistical process. The top is a picture of the Main Operating Room hallway before the *organizing benefits* and the bottom is a picture of the same hallway after.

The analysis proceeds in the following manner: first, the *inventory benefits* of kanban system is analyzed for all departments and then narrowed down by department; then, the *organizing benefits* are analyzed in a likewise manner to show its effects. The summary of the effects are presented to conclude the chapter.

3. All Departments–Analyzing Inventory benefits

Figure 9 is a plot that illustrates the average weekly costs of products for all departments over the time-span with the means and ninety-five percent confidence intervals for both before and after the kanban system was installed. There is no statistically significant difference in the costs of supplies from before the kanban organizing benefits to after. This may be due to the mixed effects that kanban has on different types of departments and/or how effective the supply chain was managed for each department. Whatever the cause, it at least implores the analysis to a deeper level by suggesting that further investigation of the effects of the kanban on each department is warranted.

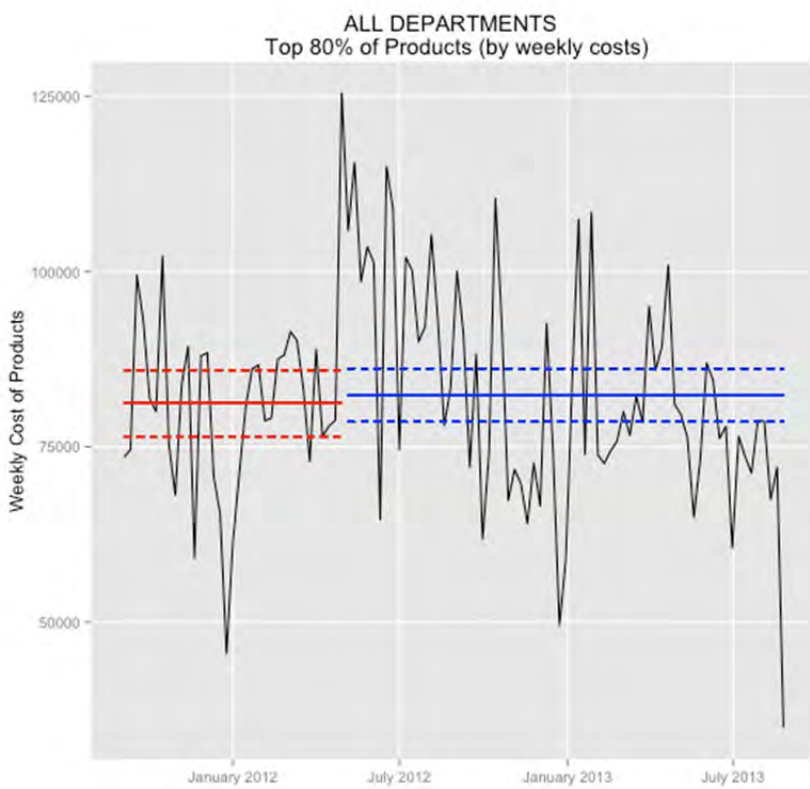

Figure 9. Plot for analysis of the *inventory benefits* of kanban. The time series is for items representing the top eighty percent of costs for all departments. The red lines are before the kanban organizing benefits and the blue for after. Note that there is no statistically significant difference from before to after the organizing benefits.

4. Individual Departments–Analyzing Inventory Benefits

Analyzing each of the department's costs over time shows a mixed result in the outcome (see Figures 10 and 11). The majority of the departments show no statistically significant change after the organizing benefits of kanban. However, there are two departments—Critical Care (4th) and the Emergency Room—that show a statistically significant decrease from the two-bin kanban system. The benefits of the *inventory benefits* of the two-bin kanban system may be limited in certain aspects. This is discussed in further detail in the next chapter.

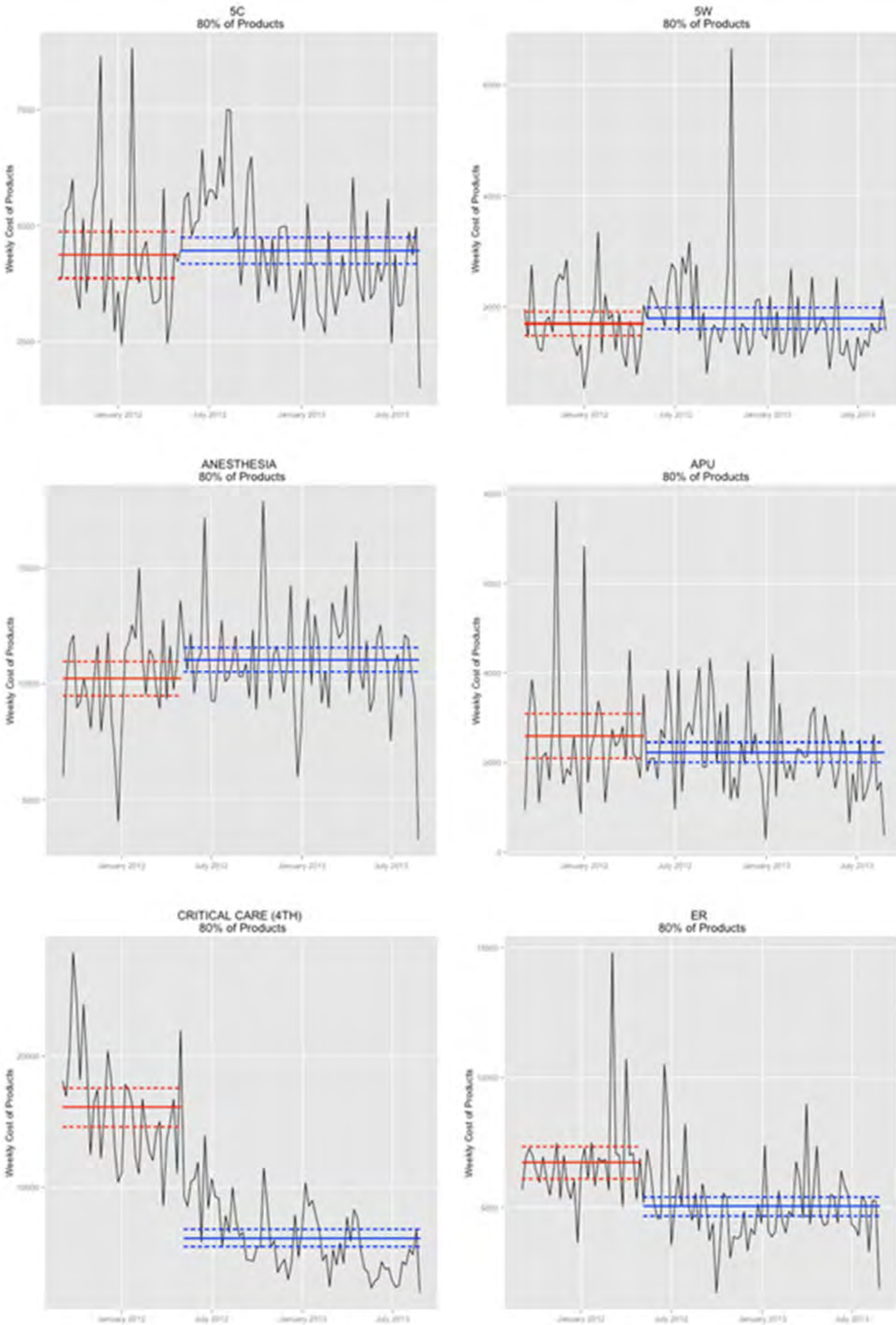

Figure 10. Costs of products plotted over time for six departments. The solid lines represent the mean and the dashed represent the ninety-five percent confidence interval. Red is before the kanban organizing benefits and blue is after.

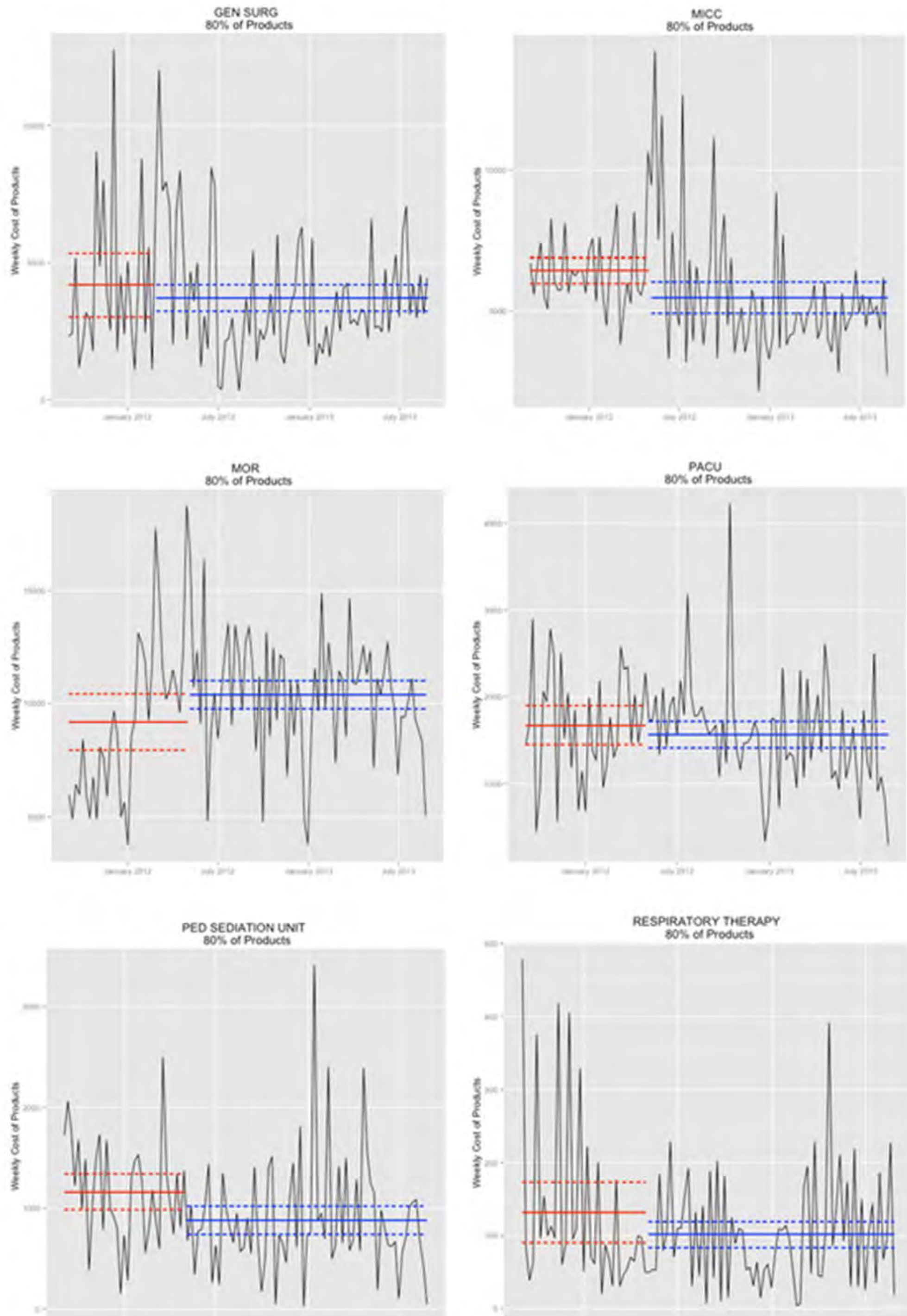

Figure 11. Continuation of department's costs of products plotted over time for the final six departments. There is no significant statistical difference from before to after for all six departments.

5. All Departments–Analyzing Organizing Benefits

We now turn our focus to the *organizing benefits* portion of the analysis. To reiterate, the last two data preparation steps—the Pareto principle and the requirement of items being present before and after the kanban system was installed—were dropped and then the exact same analysis was performed as done in the *inventory benefits* analysis portion. Similar to Figure 9, Figure 12 is a plot that illustrates the average weekly costs of products for all departments over the time-span with the means and ninety-five percent confidence intervals of both before and after the kanban system was installed. Note the positive effects that can be seen in Figure 12, where all departments are represented in the time line. What is unexpected is the degree of separation between the two means—especially considering results in Figure 9. To investigate this further, the analysis again pushes toward a focus on each department to see its weight in the overall whole.

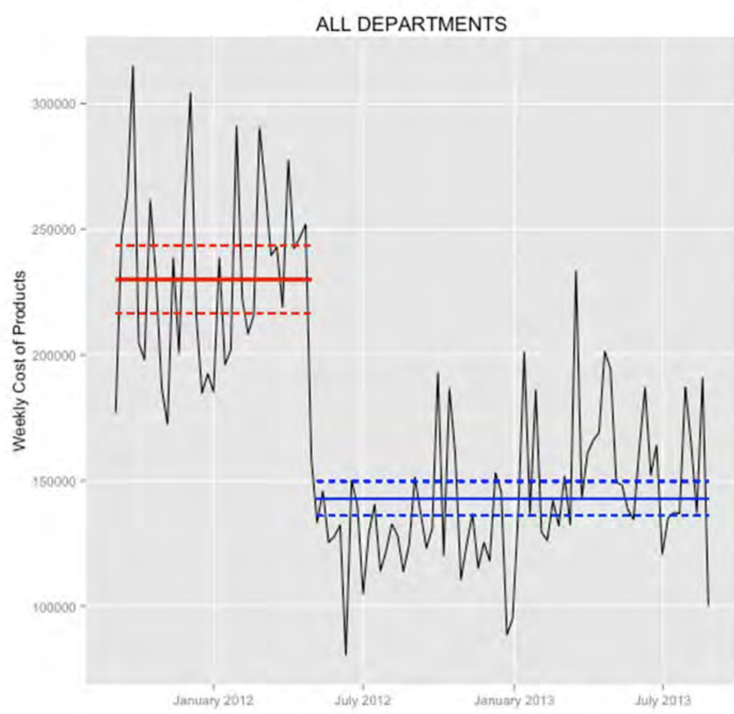

Figure 12. Plot of all departments for the organizing benefits portion of the analysis. Again, the red lines represent the data before the kanban organizing benefits and the blue after.

6. Individual Departments–Analyzing Organizing Benefits

Similar to the *inventory benefits* analysis, there is mixed results when looking at the effects by department. What is not seen in the previous section that is revealed here is a good number of statistically significant jumps or increases in costs, where the mean from after is greater than the mean before, see Figures 13 and 14. This happens in four the twelve departments. While some of the department's costs appear to jump others drop considerably. Notably, the Main Operating Room department's costs are significantly lower in this portion of the analysis than they were than in the previous analysis. Again, a discussion of possible causes occurs in the following chapter.

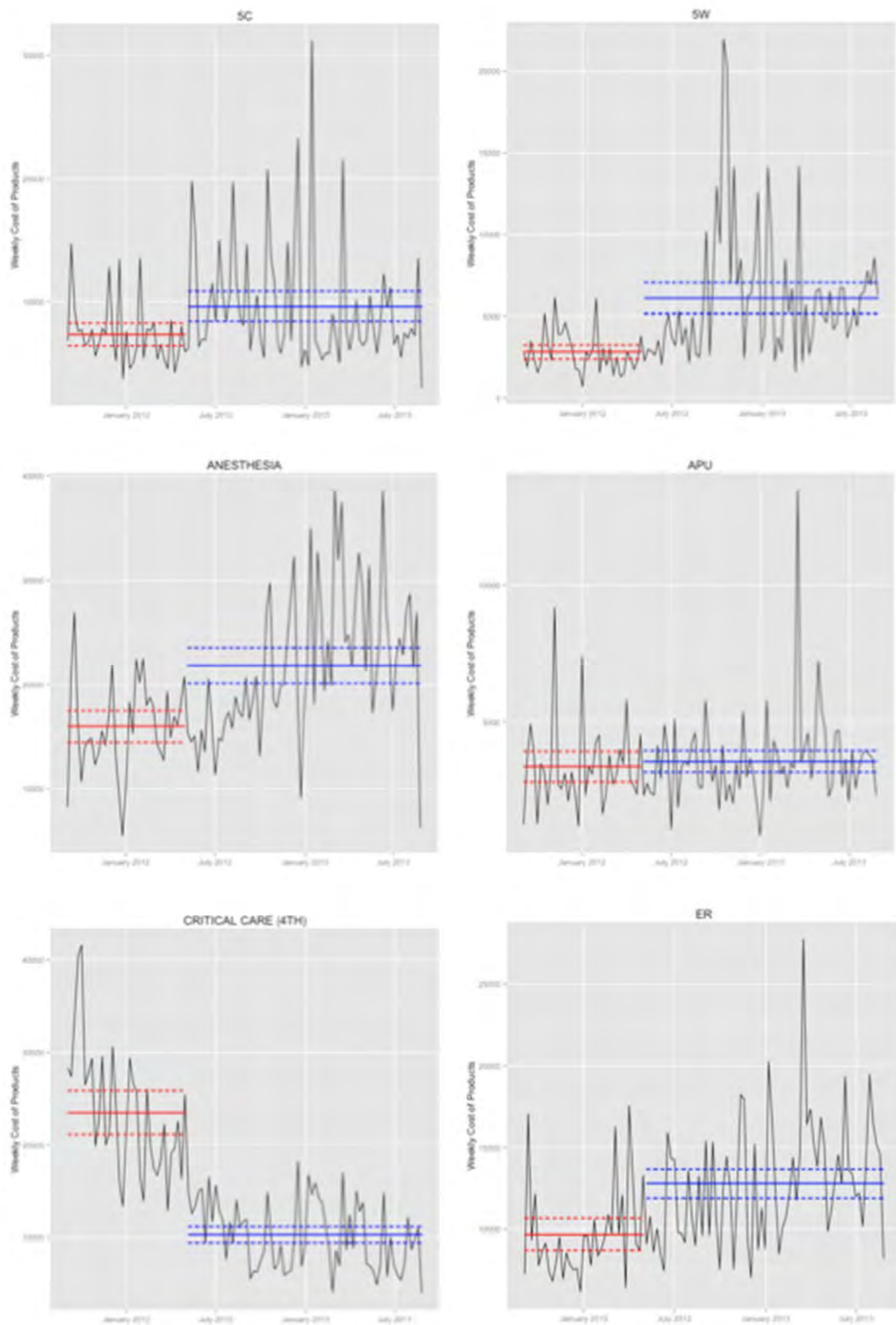

Figure 13. Department's costs over time for the organizing benefits portion of analysis. Some departments appear to have significant increases in the mean while others dropped or remained unchanged.

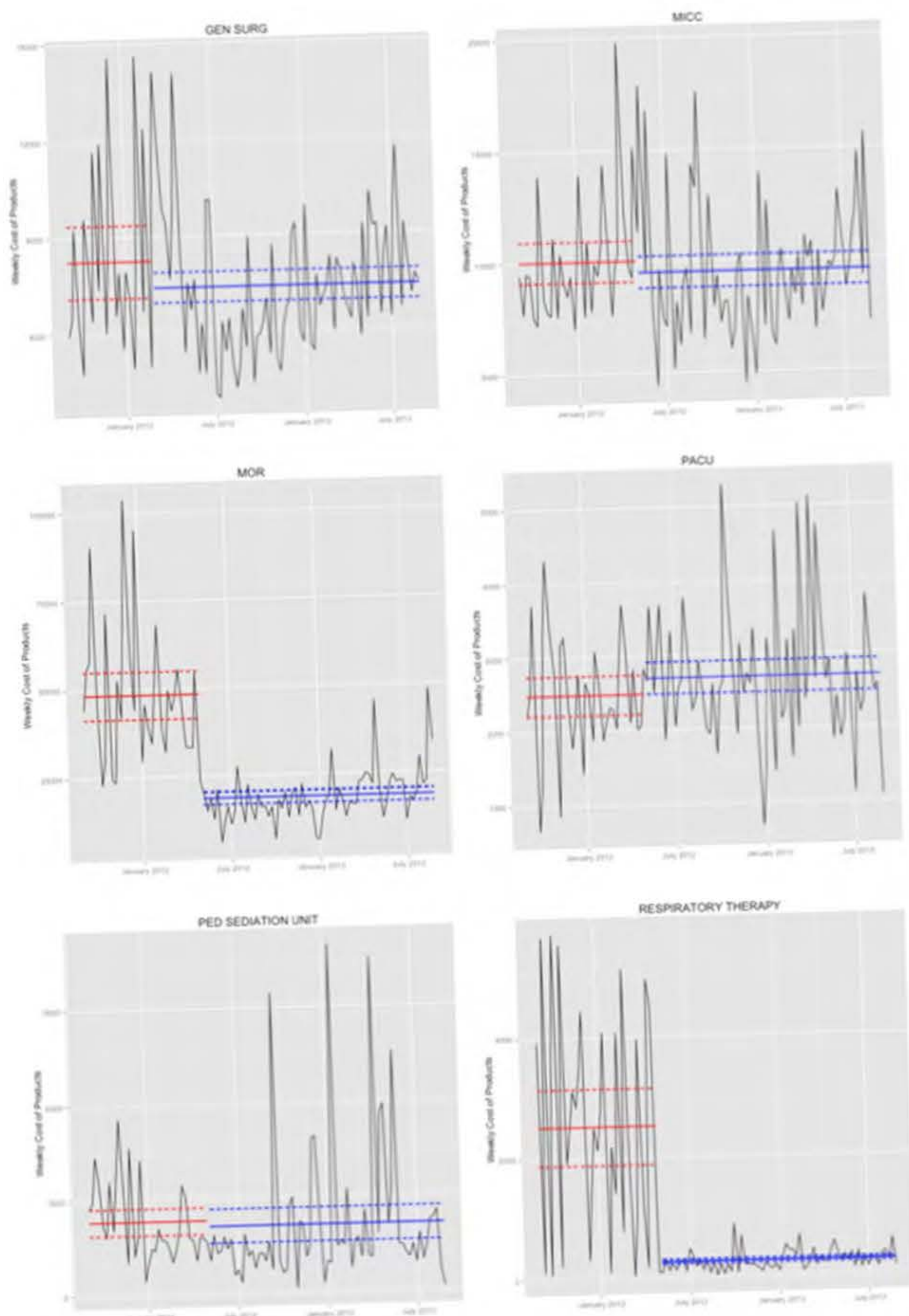

Figure 14. Continuation of department's costs over time for the organizing benefits portion of analysis. While some departments saw no difference from before, note the degree to which the MOR and Respiratory Therapy changed from the Figure 10.

7. Summary of Statistics on Kanban Impact

Here we present a summary of the effects of the two-bin kanban system. Figure 15 presents a summary of the effects for the *inventory benefits* of two-bin kanban for each department. It is easy to note that the changes made the greatest effect for only a few departments (Critical Care 4th and ER) and limited to no statistically difference for any of the other departments. Figure 16 is the *organizing benefits* portion summary. Here you further see the dramatic difference the MOR and Respiratory Therapy had from the *inventory benefits* to *organizing benefits*.

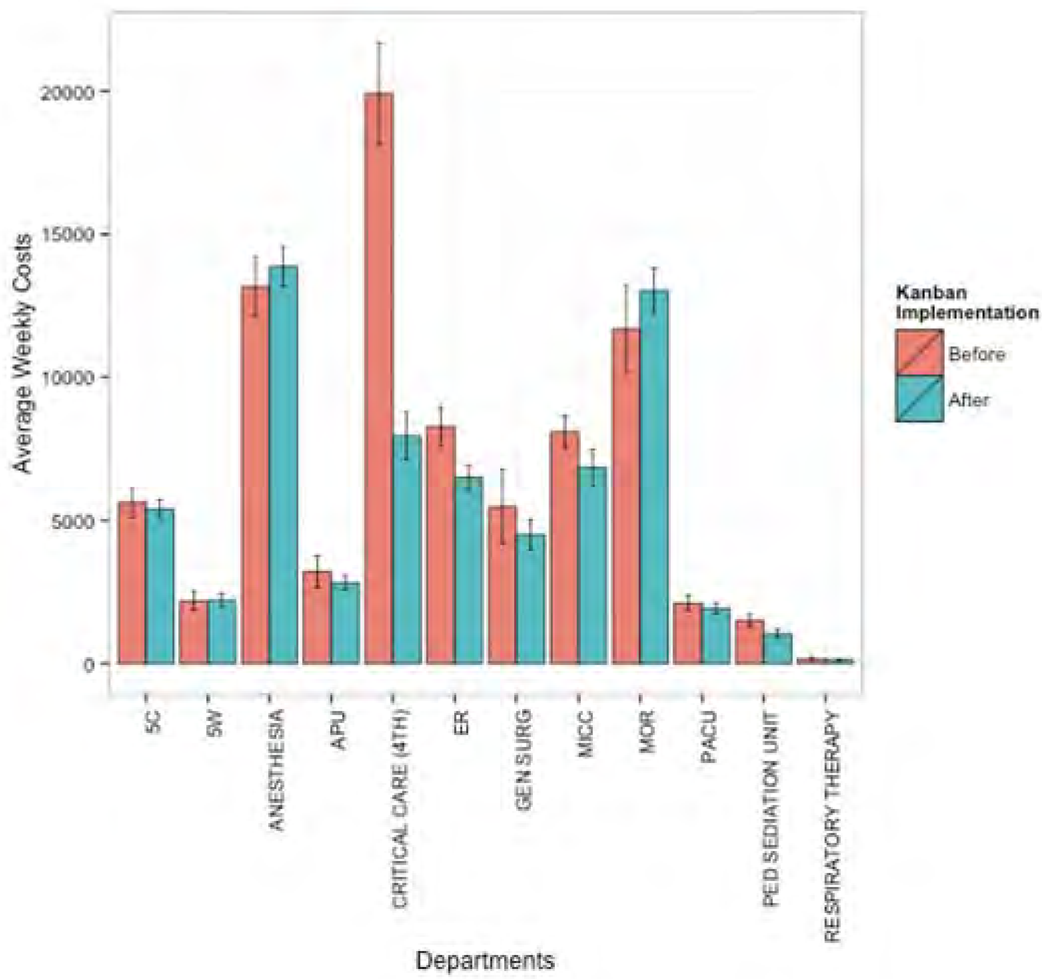

Figure 15. Summary plot for the average weekly costs of each department for the effects of the *inventory benefits* portion of the analysis of two-bin kanban. Each error bar represents a ninety-five percent confidence interval.

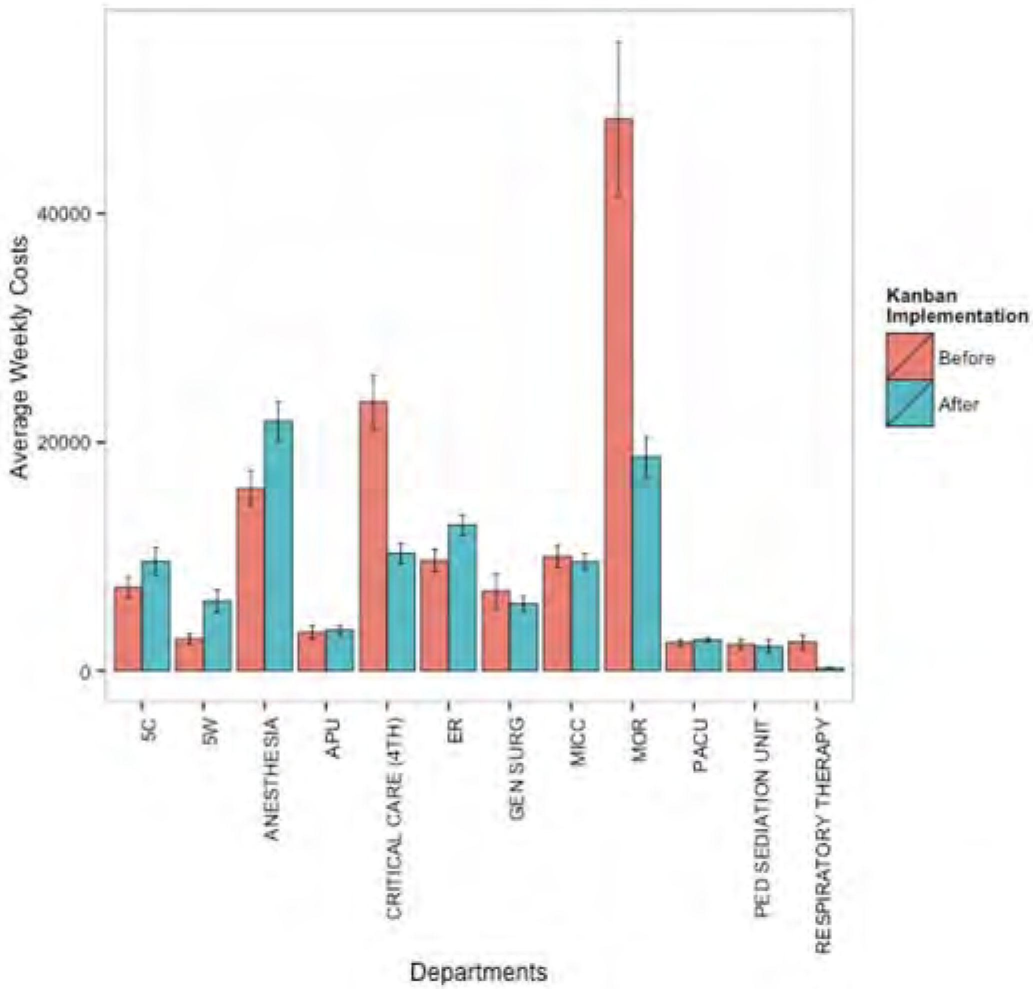

Figure 16. Summary plot for the average weekly costs of each department for the *organizing benefits* portion of the analysis of two-bin kanban. Note the significant difference for the MOR from Figure 14.

V. DISCUSSION AND FUTURE RESEARCH

Kanban is an attempt to bring a level of optimization to product availability while trying to minimize cost to the supply-chain system. At its core, the kanban card is a mechanism that signals a reorder. The two-bin system is designed to disperse the product into equally sized bins that together (between the first and second bin) capture the rates of consumption and the time necessary for the product to complete the reordering process. Together, the card and the bins are expected to regularize the intervals between ordering, regularize the amount of product being ordered, reduce the quantity of product on-hand as it sensitizes the supply-chain to demand, and organize the products for consumption and resupply. Through all these effects, it is assumed that there will be a reduction in costs.

The data we analyze shows some improvement delivered by the kanban system, but is inconclusive to show improvement across all departments. Thus, it is difficult to defend a blanket statement that the kanban system always brings savings—it brings significant savings in some cases and not in others. In this chapter we discuss the results of the analysis—for both the *organizing benefits* and the *inventory benefits*, followed by the limitations of this study, and then conclude with recommendations for future research.

A. RESULTS FROM THE ANALYSIS

The results show a significant *organizational benefit* from the kanban system, a steady-state in *inventory benefit*, and varying nuances from department to department. Specifically, Figure 12 demonstrates a significant reduction in costs due to *organizational benefit*. Figure 9 shows no change in costs due to *inventory benefit*. Finally, Figures 15 and 16 show that there is no uniform trend across all departments. In some departments, there were significant *organizational benefits* while in others there were not. Likewise, in some departments there were significant *inventory benefits*, while in others there were not. And, while only a few departments saw benefits, there are limitations to the scope and data presented in this thesis, which may provide further insight. In this section, we discuss these results and break down the discussion first for the *organizing benefits* and then for the *inventory benefits*.

1. Discussion of Organizing Benefits

The kanban system is designed, at least in part, to organize the items ordered. During this organizational process, the buyer is focused on each item purchased and will often question the continuance of purchasing the item. If the item is duplicative or worthless, it can and should be eliminated. This is the reduction seen in the MOR, where unneeded items from organizing the supply-chain provided great benefit, see Figure 14. Exploring this further, Figure 17 illustrates items ordered by MOR before the kanban system installed (at least ten times), but not ordered at all afterward. These items were eliminated from the MOR's inventory during the *organizing benefit* stage. Figure 17 also illustrates that there were many items, varying in cost, that were unduly being ordered.

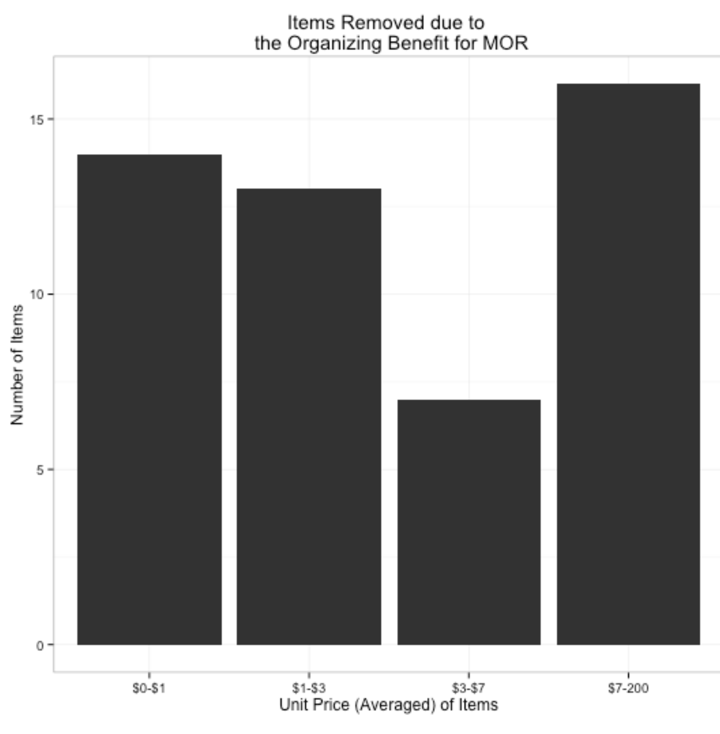

Figure 17. Histogram of items removed due to the *organizing benefit* for MOR. Note that the organization effect is across items of a variety of unit price.

While many departments will benefit from figuring out bin assignments and periodic automatic replenishment (PAR) levels, how much success in organizing a department has, depends upon the current operating procedures of the supply stock. If the department already fastidiously manages the supply stocks, then the gains from a two-bin kanban *organizing benefits* is not expected to be as high. This may provide an explanation to why some departments experience a drop in the average weekly costs of items ordered and others did not. As mentioned, in the case of WRNMMC, there are numerous external factors during the installation of the kanban system. Some of these factors include the introduction of additional personnel, the construction of new and/or enlarged working spaces, the melding of work culture. All may have had influences on the outcomes of the kanban system's performance—for better or worse.

Furthermore, when the analysis focused on the *organizing benefits* portion of the kanban system, there were four departments whose weekly average costs of supplies were statistically higher than prior to the kanban system, see Table 2. These higher shifts may be due to changes in purchasing patterns or in the operations of the department, such as which department should order specific items.

Department	Before		After		Change
	Mean	Upper 95% CI / Lower 95% CI	Mean	Upper 95% CI / Lower 95% CI	
5C	$6,214	$6,827 / $5,600	$8,291	$9,505 / $7,078	Higher
5W	$2,458	$2,846 / $2,070	$5,338	$6,272 / $4,403	Higher
ANESTHESIA	$13,496	$14,595 / $12,398	$16,447	$17,457 / $15,438	Higher
ER	$9,008	$9,781 / $8,235	$10,952	$11,632 / $10,273	Higher
APU	$3,222	$3,777 / $2,667	$2,865	$3,116 / $2,613	None
GEN SURG	$5,657	$6,954 / $4,359	$5,021	$5,601 / $4,441	None
MICC	$8,177	$8,796 / $7,558	$7,242	$7,931 / $6,553	None
PACU	$2,187	$2,464 / $1,910	$2,265	$2,466 / $2,063	None
PED SEDIATION UNIT	$1,562	$1,792 / $1,332	$1,492	$1,953 / $1,030	None
CRITICAL CARE (4TH)	$20,135	$21,933 / $18,337	$8,962	$9,809 / $8,115	Lower
MOR	$51,157	$61,088 / $41,226	$18,987	$21,960 / $16,014	Lower
RESPIRATORY THERAPY	$2,225	$2,352 / $2,098	$154	$183 / $126	Lower

Table 2. List of the department's average weekly costs before and after the kanban system was implemented when analyzed through *organizing benefits*.

2. Discussion of Inventory Benefits

Only two departments, the Critical Care 4th and Emergency Room, saw statistical improvements in the *inventory benefits* analysis. Unlike the *organizing benefits* it is unclear why these two are the only ones who experienced a drop in change. Speculation around the efficiency of the department supply-chain's operating procedures prior to the implementation can be made but there is no clear answer.

Furthermore, during this portion of the analysis, there were certain behaviors that we were expecting from the kanban system. The *inventory benefits* attempt to introduce economic order quantity (EOQ) to the supply-chain process. The EOQ attempts to find an optimal balance between the fixed cost of ordering and the variable cost of holding the inventory by ordering the same quantity Q every time. If h is the holding cost per unit of time, λ is the rate of demand, and K is the fixed cost of ordering the item, then it has been shown that the order quantity Q, per unit time, is

$$Q = \sqrt{\frac{2K\lambda}{h}} \ .$$

Given that the constants on the right hand side of the equation are known, the objective then the above value of Q minimizes the average cost per time per item per department (Nahmias, 2009).

The difficulty in assessing the kanban system using EOQ during the analysis with our data set is the prevalence of unknown values. Computing the demand, λ, can be done by dividing the total quantity ordered by the total time period. This at least would give an estimate of lambda. The fixed setup costs K are unknown but it is assumed that they would be constant for all items. The holding costs can be calculated as a percentage p multiplied by the cost of the item. Again, though, what value p should take is unknown.

It was expected that the effects of EOQ would be present in the system after the kanban was installed, but this is not the case. Figure 18 shows the amount of products ordered each time after the kanban system was installed. Frequency is expected to vary because demand is not constant, yet the amount of product varies with each order. This is unexpected. The reorder amount for each department should be the size of the primary bin, in most cases, or the size of both bins in extraordinary cases. However, Figure 18 shows at least four different consistently reorder amounts—four, five, eight and ten. Why this behavior is present in the two-bin kanban system is puzzling. Future implementations of the kanban system should take full advantage of this link to EOQ and should ensure that it is implemented for all items and that all order quantities should always be the same per department per item.

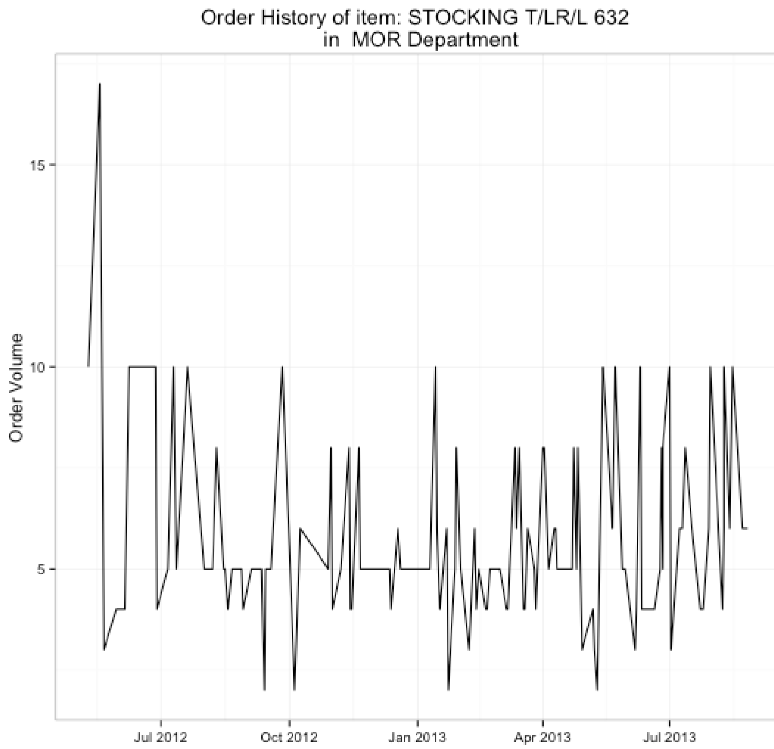

Figure 18. Timeline showing the volume of product ordered in one department after the kanban system was installed. We expected the amount of product ordered to constant, but it varied. This is a sign that the departments are not taking advantage of EOQ orders for the items in the kanban system.

3. Summary

From all this, we conclude, first that there are statistically significant *organizational benefits* to the hospital overall. This is not true on a per-department level, but it is true of the most critical departments. The savings in those departments overwhelm small increases in others. Second, there is further room for exploiting the kanban system to optimize inventory sizes. The current system does not implement EOQs per item per department. However, the kanban system provides a perfect framework to implement EOQ, thus minimizing operating costs of the logistic system. We recommend that EOQs be explored in future refinements to the kanban system.

B. LIMITATIONS AND FUTURE WORK

There are several effects that have limited the scope of this analysis. The first is the external circumstances that instigated the implementation of the kanban system. While we controlled, in part, the uptick of supplies as the two hospitals were combining, it would have been preferred to have a static homogenous population prior to the installment of the kanban system. This at least would have reduced the possibility of confounding external effects. Furthermore, what was not mentioned, but happened over the course of this time period, was the introduction of departments to newly constructed areas as the footprint of the old Bethesda hospital expanded to accommodate new patients and staff. As the number of hospital beds or provider numbers increased or, at the very least, changed, it had to have had an effect on the supplies ordered for a department. This can be seen in the density plot of Figure 5, which shows the statistical changes in the data leading up to the implementation of the kanban installation. While we noted that the majority of the increase in the frequency occurred in the summer of 2011, there were a few departments that saw their increases in frequency occurring in the fall of 2011 or well into the spring of 2012.

The second limitation is the data set. Within the data we were missing several months of order history for several clinics/departments. These departments were left out of the analysis and may have provided further insight. Furthermore, the source of the data set had confounding effects. While we have tried to mitigate the effects of DMLSS being a universal medical logistics software and data collection system, ideally it would have been preferred to have a data set that clearly articulated which items are affected in kanban analysis from before to after. This would have mitigated the possibility of statistical noise.

Finally, it would have been preferred to match the department codes in the DMLSS data set with some type of workload number for each department (such as, number of patients seen). If we were able to see the workload data by department, we would have been able to account for any increases in supply costs associated with an increase in workload. Alas, we were left to assume a constant patient workload for all departments.

1. Analysis Not Performed

Outside of the limitations, there were aspects of this kanban system that were not analyzed. Though discussed briefly during the overview of the kanban system, the aspects of the RFID capabilities of the two-bin kanban system were not addressed in this thesis. The greatest impact that the RFID capabilities would have will be on reducing the involvement of humans within the supply-chain loop. There was no data related to the effects of RFID to analyze, therefore the RFID capabilities were not analyzed. Similarly, Landry and Beaulieu indicate potential savings of the RFID two-bin kanban system is time spent by clinicians and material handlers in the supply-chain process (Landry & Beaulieu, 2010). The data analyzed did not cover this or any portion of the cost-savings attributable to reducing the amount of manpower dedicated to the supply-chain. Therefore, again, it was not analyzed. However, we believe that further analysis involving the order costs, the manpower reduction in ordering, and EOQ would highlight further potential for the kanban system to improve the logistics process.

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